

WIDE-ANGLE LENS SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The present invention relates to a wide-angle lens system having a long back focal distance suitable for an electronic still camera.

2. Description of the Prior Art

10 In an electronic still camera which utilizes a solid-state image sensor such as a CCD, miniaturization and higher definition of imaging devices have progressed, and accordingly, a wide-angle lens system having a short focal length has become increasingly in demand. In
15 addition, in such an electronic still camera, in order to provide optical elements, such as a low-pass filter, an infra-red filter, and a beam splitter, etc., between the photographing lens system and the imaging device, a long back focal distance is required. However, in a wide-angle
20 lens system, it is difficult to obtain both a long back focal distance and a desirable optical performance.

SUMMARY OF THE INVENTION

25 The present invention provides a wide-angle lens system having an f-number of approximately 2.8, having good

optical performance at a half angle-of-view of 30° or more at the short focal length extremity, and having a back focal distance sufficiently longer than the focal length of the entire lens system.

5 According to an aspect of the present invention, there is provided a wide-angle lens system including a first lens group having a negative refractive power (hereinafter, a negative first lens group), and a second lens group having a positive refractive power (hereinafter, 10 a positive second lens group), in this order from the object. The negative first lens group and the positive second lens group are positioned so that the distance between the negative first lens group and the positive second lens group is set as the maximum distance in the wide-angle lens 15 system. The wide-angle lens system satisfies the following conditions:

$$2.0 < f_B/f < 2.5 \quad \dots \quad (1)$$

$$4.5 < |f_1/f| < 6.2 \quad \dots \quad (2)$$

$$1.8 < f_2/f < 2.0 \quad \dots \quad (3)$$

20 $1.0 < d/f < 1.5 \quad \dots \quad (4)$

wherein

f_B designates the back focal distance of the wide-angle lens system;

f designates the focal length of the entire wide-
25 angle lens system;

f_1 designates the focal length of the negative first lens group;

f_2 designates the focal length of the positive second lens group; and

5 d designates the axial distance between the negative first lens group and the positive second lens group.

Three negative lens elements are preferably provided in the negative first lens group, and the three lens elements satisfy the following conditions:

10 $|\phi_{n-3}| < |\phi_{n-1}| < |\phi_{n-2}| \quad \dots \quad (5)$

$$v_{n-3} < v_{n-1} < v_{n-2} \quad \dots \quad (6)$$

$$31.0 < (v_{n-1} + v_{n-3})/2 < 38.0 \quad \dots \quad (7)$$

wherein

ϕ_{n-1} , ϕ_{n-2} , and ϕ_{n-3} designate optical powers
15 (hereinafter, power) of the three negative lens elements in this order from the object; and

v_{n-1} , v_{n-2} , and v_{n-3} designate Abbe numbers of the three negative lens elements in this order from the object.

The wide-angle lens system can satisfy the following
20 conditions:

$$0.7 < f_1/r_{12} < 1.2 \quad \dots \quad (8)$$

$$0.7 < f_1/r_{21} < 1.2 \quad \dots \quad (9)$$

$$|(r_{12} - r_{21})/(r_{12} + r_{21})| < 0.1 \quad \dots \quad (10)$$

wherein

25 r_{12} designates the radius of curvature of the most

image-side surface of the negative first lens group; and

r_{21} designates the radius of curvature of the most object-side surface of the positive second lens group.

The negative first lens group can include a negative
5 meniscus lens element having the convex surface facing toward the object, a biconvex positive lens element, a negative meniscus lens element having the convex surface facing toward the object, a biconcave negative lens element, and a biconvex positive lens element, in this order from
10 the object.

The positive second lens group can include, for example, cemented lens elements having a negative lens element and a positive lens element, and a positive lens element, in this order from the object.

15 In the wide-angle lens system, a diaphragm is preferably provided behind the positive second group for the purpose of simplifying the mechanical structure of the wide-angle lens system. In this case, the diaphragm can be provided in the camera body.

20 On the other hand, for the purpose of securing both a higher optical performance and sufficient peripheral illumination, the diaphragm is preferably provided between the negative first lens group and the positive second lens group.

25 The present disclosure relates to subject matter

contained in Japanese Patent Application No. 2003-14896
(filed on January 23, 2003) which is expressly incorporated
herein in its entirety.

5 BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be discussed below in
detail with reference to the accompanying drawings, in
which:

Figure 1 is a lens arrangement of the wide-angle lens
10 system according to a first embodiment of the present
invention;

Figures 2A, 2B, 2C, 2D and 2E show aberrations
occurred in the lens arrangement shown in figure 1;

Figure 3 is a lens arrangement of the wide-angle lens
15 system according to a second embodiment of the present
invention;

Figures 4A, 4B, 4C, 4D and 4E show aberrations
occurred in the lens arrangement shown in figure 3;

Figure 5 is a lens arrangement of the wide-angle lens
20 system according to a third embodiment of the present
invention;

Figures 6A, 6B, 6C, 6D and 6E show aberrations
occurred in the lens arrangement shown in figure 5;

Figure 7 is a lens arrangement of the wide-angle lens
25 system according to a fourth embodiment of the present

invention; and

Figures 8A, 8B, 8C, 8D and 8E show aberrations occurred in the lens arrangement shown in figure 7.

5 DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in the first through fourth embodiments shown in figures 1, 3, 5 and 7, respectively, the wide-angle lens system includes a negative first lens group 10, and a positive second lens group 20, in this order from the
10 object. The negative first lens group 10 and the positive second lens group 20 are positioned so that the distance between the negative first lens group 10 and the positive second lens group 20 is set as the maximum distance in the wide-angle lens system.

15 In the first through third embodiments (figures 1, 3 and 5), a diaphragm S is provided behind the positive second lens group 20 (i.e., being behind all the lens groups).

In the fourth embodiment (figure 7), the diaphragm
20 S is provided between the negative first lens group 10 and the positive second lens group 20.

In each of the first through fourth embodiments, a filter group (or, an optical-path splitting device) 30 is provided behind the positive second lens group 20.

25 Condition (1) relates to the back focal distance and

the focal length of the entire wide-angle lens system.

If f_B/f exceeds the lower limit of condition (1), it becomes difficult to insert optical elements such as a low-pass filter(s) or a beam splitter behind the positive
5 second lens group 20.

If f_B/f exceeds the upper limit of condition (1), the back focal distance becomes too long, and the diameter of the diaphragm S and that of the entire lens groups (especially, the diameter of the positive second lens group
10 20) become larger. Consequently, miniaturization of the wide-angle lens system becomes difficult. In particular, if f_B/f exceeds the upper limit of condition (1) under the condition that the diaphragm S is provided behind the positive second lens group 20, the drawbacks (i.e., the
15 too long back focal distance, and the larger diameters of the diaphragm S and the entire lens groups) mentioned above may occur excessively, because the back focal distance and the diameter of the diaphragm S are in a proportional relationship.

20 Conditions (2) and (3) specify the powers of the negative first lens group 10, the positive second lens group 20 and the entire lens system.

If $|f_1/f|$ exceeds the lower limit of condition (2), the negative power of the negative first lens group 10
25 becomes too strong. As a result, it is advantageous to

secure a longer back focal distance with respect to the focal length of the entire wide-angle lens system; however, aberrations occurred in the negative first lens group 10 cannot be corrected.

5 If $|f_1/f|$ exceeds the upper limit of condition (2), a sufficient back focal distance cannot be secured.

 If f_2/f exceeds the lower limit of condition (3), the positive power of the positive second lens group 20 becomes too strong. As a result, aberrations occurred in 10 the positive second lens group 20 cannot be corrected, and it becomes difficult to secure a sufficient back focal distance.

 If f_2/f exceeds the upper limit of condition (3), the overall length of the wide-angle lens system becomes 15 longer, so that miniaturization of the wide-angle lens system cannot be achieved.

 Condition (4) specifies the distance between the negative first lens group 10 and the positive second lens group 20.

20 If d/f exceeds the lower limit of condition (4), a sufficient back focal distance cannot be secured, and aberrations cannot be adequately corrected.

 If d/f exceeds the upper limit of condition (4), the overall length of the wide-angle lens system becomes 25 longer, and miniaturization of the wide-angle lens system

becomes difficult.

In addition, in the case where three negative lens elements are provided in the negative first lens group 10, occurrence of lateral chromatic aberrations can be reduced by determining the most appropriate Abbe numbers for each of the three negative lens elements.

Furthermore, in order to reduce occurrence of higher order aberrations, the radius of curvature of the most image-side surface of the negative first lens group 10, and the radius of curvature of the most object-side surface of the positive second lens group 20, i.e., the radius of curvatures of the directly facing lens surfaces of these lens groups, are adequately determined, which will be explained in detail.

Conditions (5), (6) and (7) relates to the three negative lens elements in the case where these negative lens elements are provided in the negative first lens group 10.

Out of the three negative lens elements, if the power of the most object-side negative lens element becomes stronger, the negative distortion largely progresses in the positive direction as the height of an image increases, so that distortion undesirably shows a typical distortion-curve like the combination of the barrel-type distortion and the pin-cushion type distortion.

On the other hand, the most image-side negative lens element is arranged to correct lateral chromatic aberration. Accordingly, if the power of the most image-side negative lens element becomes too strong, coma and astigmatism largely occur.

In order to suitably correct lateral chromatic aberration, it is preferable that the Abbe number of the negative lens element having the strongest power be larger, and that of the negative lens element having the weakest power be smaller.

Furthermore, in order to reduce occurrence of lateral chromatic aberration at the peripheral portion of each negative lens element, it is preferable that condition (7) be satisfied.

Conditions (8), (9) and (10) specify the radius of curvatures of the directly facing surfaces of the negative first lens group 10 and the positive second lens group 20. Namely, these conditions relate to the radius of curvature of the most image-side surface of the negative first lens group 10, and the radius of curvature of the most object-side surface of the positive second lens group 20.

The feature of the above-explained arrangement of the lens surfaces is that the curvature of the final surface of the negative first lens group 10 and the curvature of the first surface of the positive second lens group 20 are

arranged to have the center of curvature thereof on the object side.

Due to the above arrangement, the excessive over-correction of aberrations can be prevented, and, in particular, the occurrence of higher-order spherical aberration can be reduced.

If $f1/r12$ exceeds the upper limit of condition (8), and if $f1/r21$ exceeds the upper limit of condition (9), the center of curvature is moved toward the image. Consequently, higher-order aberrations tend to occur.

If $f1/r12$ exceeds the lower limit of condition (8), and if $f1/r21$ exceeds the lower limit of condition (9), aberrations are under-corrected.

Furthermore, since the distance between the negative first lens group 10 and the positive second lens group 20 is sufficiently long, condition (10) is preferably satisfied in order to reduce the occurrence of higher-order spherical aberration and coma.

Specific numerical data of the embodiments will be described hereinafter.

In the diagrams showing spherical aberration and the sine condition, SA designates spherical aberration, and SC designates the sine condition.

In the diagrams of chromatic aberration represented by spherical aberration, the solid line and the two

types of dotted lines respectively indicate spherical aberrations with respect to the d, g and C lines.

In the diagrams of lateral chromatic aberration, the two types of dotted lines respectively indicate magnification with respect to the g and C lines; however, the d line as the base line coincides with the ordinate.

In the diagrams of astigmatism, S designates the sagittal image, and M designates the meridional image.

In the tables, F_{no} designates the f-number, f designates the focal length of the entire wide-angle lens system, f_b designates the back focal distance (the equivalent air thickness along the optical axis from the most image-side surface of the positive second lens group to the image plane), W designates the half angle-of-view ($^\circ$), r designates the radius of curvature, d designates the lens-element thickness or distance between lens elements, N_d designates the refractive index of the d-line, and v designates the Abbe number.

[Embodiment 1]

Figure 1 is the lens arrangement of the wide-angle lens system according to the first embodiment of the present invention. Figures 2A through 2E show aberrations occurred in the lens arrangement shown in figure 1.

The negative first lens group 10 is constituted by

a negative meniscus lens element 11 having the convex surface facing toward the object, a biconvex positive lens element 12, a negative meniscus lens element 13 having the convex surface facing toward the object, a biconcave negative lens element 14, and a biconvex positive lens element 15, in this order from the object.

The positive second lens group 20 is constituted by cemented lens elements having a negative lens element 21 and a positive lens element 22, and a positive lens element 23, in this order from the object.

A plane-parallel plate (filter group) 30 is provided in front of the imaging plane.

Table 1 shows the numerical data of the first embodiment; and note that the plane-parallel plate 30 is considered in the above numerical data.

The diaphragm S is provided 1.00 mm behind (on the image side) the second lens group 20 (surface No. 15). Since the diaphragm S is provided behind the positive second lens group 20, the mechanical structure of the wide-angle lens system can be simplified, and a sufficiently high optical performance can be maintained. Furthermore, in a camera having an exchangeable lens barrel, it is possible to fix the diaphragm S on the camera body side (i.e., without having a diaphragm in the lens barrel).

[Table 1]

FNO. = 1:2.8

f = 6.50

W = 32.2

5 fB = 15.45 (=4.35 + 9.00/1.51633 + 3.00 + 3.29/1.51633)

	Surf. No.	r	d	Nd	vd
	1	17.983	1.00	1.72342	/ 38.0
	2	9.184	2.31		
	3	54.874	2.28	1.75520	/ 27.5
10	4	-27.827	0.21		
	5	26.380	1.00	1.77250	/ 49.6
	6	5.539	1.98		
	7	-104.707	1.39	1.72825	/ 28.5
	8	54.943	3.53		
15	9	21.878	3.50	1.80518	/ 25.4
	10	-37.751	7.24		
	11	-34.158	1.00	1.80518	/ 25.4
	12	9.041	2.08	1.51742	/ 52.4
	13	-10.761	0.20		
20	14	19.207	1.55	1.69680	/ 55.5
	15	-17.116	4.35		
	16	∞	9.00	1.51633	/ 64.1
	17	∞	3.00		
	18	∞	3.29	1.51633	/ 64.1
25	19	∞	-		

[Embodiment 2]

Figure 3 is the lens arrangement of the wide-angle lens system according to the second embodiment of the present invention. Figures 4A through 4E show aberrations
 5 occurred in the lens arrangement shown in figure 3. Table 2 shows the numerical data of the second embodiment. The diaphragm S is provided 1.00 mm behind (on the image side) the second lens group 20 (surface No. 15). The basic lens arrangement of the second embodiment is the same as that
 10 of the first embodiment.[Table 2]

$$FNO. = 1:2.8$$

$$f = 6.50$$

$$W = 32.3$$

$$fB = 15.42 (=4.31 + 9.00/1.51633 + 3.00 + 3.29/1.51633)$$

15	Surf. No.	r	d	Nd	vd
	1	17.911	1.00	1.72000 / 42.0	
	2	9.182	2.32		
	3	56.186	2.27	1.75520 / 27.5	
	4	-27.821	0.20		
20	5	25.691	1.00	1.77250 / 49.6	
	6	5.511	1.91		
	7	-117.079	1.94	1.72825 / 28.5	
	8	59.244	3.15		
	9	22.134	3.50	1.80518 / 25.4	
25	10	-43.955	7.07		

	11	-40.833	1.00	1.80518 / 25.4
	12	9.186	2.08	1.51742 / 52.4
	13	-10.794	0.20	
	14	19.777	1.77	1.69680 / 55.5
5	15	-17.082	4.31	
	16	∞	9.00	1.51633 / 64.1
	17	∞	3.00	
	18	∞	3.29	1.51633 / 64.1
	19	∞	-	

10 [Embodiment 3]

Figure 5 is the lens arrangement of the wide-angel lens system according to the third embodiment of the present invention. Figures 6A through 6E show aberrations occurred in the lens arrangement shown in figure 5. Table
15 3 shows the numerical data of the third embodiment. The diaphragm S is provided 1.00 mm behind (on the image side) the second lens group 20 (surface No. 15). The basic lens arrangement of the third embodiment is the same as that of the first embodiment.

20 [Table 3]

$$\text{FNO.} = 1:2.8$$

$$f = 6.50$$

$$W = 32.3$$

$$fB = 15.58 (=4.47 + 9.00/1.51633 + 3.00 + 3.29/1.51633)$$

25	Surf. No.	r	d	Nd	vd
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	1	18.280	1.00	1.72000 / 42.0
	2	9.134	2.31	
	3	53.305	2.29	1.75520 / 27.5
	4	-27.857	0.23	
5	5	26.152	1.00	1.74320 / 49.3
	6	5.469	1.92	
	7	-99.554	1.63	1.71736 / 29.5
	8	52.749	3.26	
	9	23.367	3.50	1.80518 / 25.4
10	10	-39.327	7.22	
	11	-39.649	1.00	1.80518 / 25.4
	12	9.237	2.09	1.51742 / 52.4
	13	-10.710	0.20	
	14	19.825	1.55	1.69680 / 55.5
15	15	-17.353	4.47	
	16	∞	9.00	1.51633 / 64.1
	17	∞	3.00	
	18	∞	3.29	1.51633 / 64.1
	19	∞	-	

20 [Embodiment 4]

Figure 7 is the lens arrangement of the wide-angle lens system according to the fourth embodiment of the present invention. Figures 8A through 8E show aberrations occurred in the lens arrangement shown in figure 7. Table
25 4 shows the numerical data of the fourth embodiment. The

diaphragm S is provided 3.423 mm behind (on the image side) the first lens group 10 (surface No. 10). The basic lens arrangement of the fourth embodiment is the same as that of the first embodiment. By providing the diaphragm S between the negative first lens group 10 and the positive second lens group 20, a high optical performance can be maintained, and peripheral illumination can be easily collected.

[Table 4]

10 FNO. = 1:2.8

f = 6.50

W = 32.3

fB = 15.30 (=4.20 + 9.00/1.51633 + 3.00 + 3.29/1.51633)

	Surf. No.	r	d	Nd	vd
15	1	17.677	1.00	1.72342 / 38.0	
	2	9.258	2.26		
	3	50.599	2.26	1.75520 / 27.5	
	4	-30.512	0.25		
	5	23.349	1.00	1.77250 / 49.6	
20	6	5.547	1.88		
	7	-110.987	1.54	1.72825 / 28.5	
	8	38.181	3.24		
	9	20.654	3.50	1.80518 / 25.4	
	10	-41.440	7.78		
25	11	-36.852	1.00	1.80518 / 25.4	

	12	9.409	2.05	1.51742 / 52.4
	13	-10.706	0.20	
	14	17.971	1.54	1.69680 / 55.5
	15	-18.362	4.20	
5	16	∞	9.00	1.51633 / 64.1
	17	∞	3.00	
	18	∞	3.29	1.51633 / 64.1
	19	∞	-	

Table 5 shows the numerical values for each condition
 10 for each embodiment.

[Table 5]

	Cond.(1)	Cond.(2)	Cond.(3)	Cond.(4)	Cond.(5)
Embod.1	2.38	6.02	1.94	1.11	Satisfied
Embod.2	2.37	4.82	1.90	1.09	Satisfied
15 Embod.3	2.40	4.80	1.91	1.11	Satisfied
Embod.4	2.35	5.05	1.89	1.20	Satisfied
	Cond.(6)	Cond.(7)	Cond.(8)	Cond.(9)	Cond.(10)
Embod.1	Satisfied	33.3	1.04	1.15	0.050
Embod.2	Satisfied	35.3	0.71	0.77	0.037
20 Embod.3	Satisfied	35.8	0.79	0.79	0.004
Embod.4	Satisfied	33.3	0.79	0.89	0.059

As can be understood from Table 5, each
 embodiment satisfies each condition, and as can be
 understood from the drawings, the various aberration are
 25 adequately corrected.

According to the above description, a wide-angle lens system, having (i) an f-number of approximately 2.8, (ii) good optical performance at a half angle-of-view of 30° or more at the short focal length extremity, and (iii) 5 a back focal distance sufficiently longer than the focal length of the entire lens system, can be obtained.